



Climate Milestone: Earth's CO2 Level Passes 400 ppm

Greenhouse gas highest since the Pliocene, when sea levels were higher and the Earth was warmer.

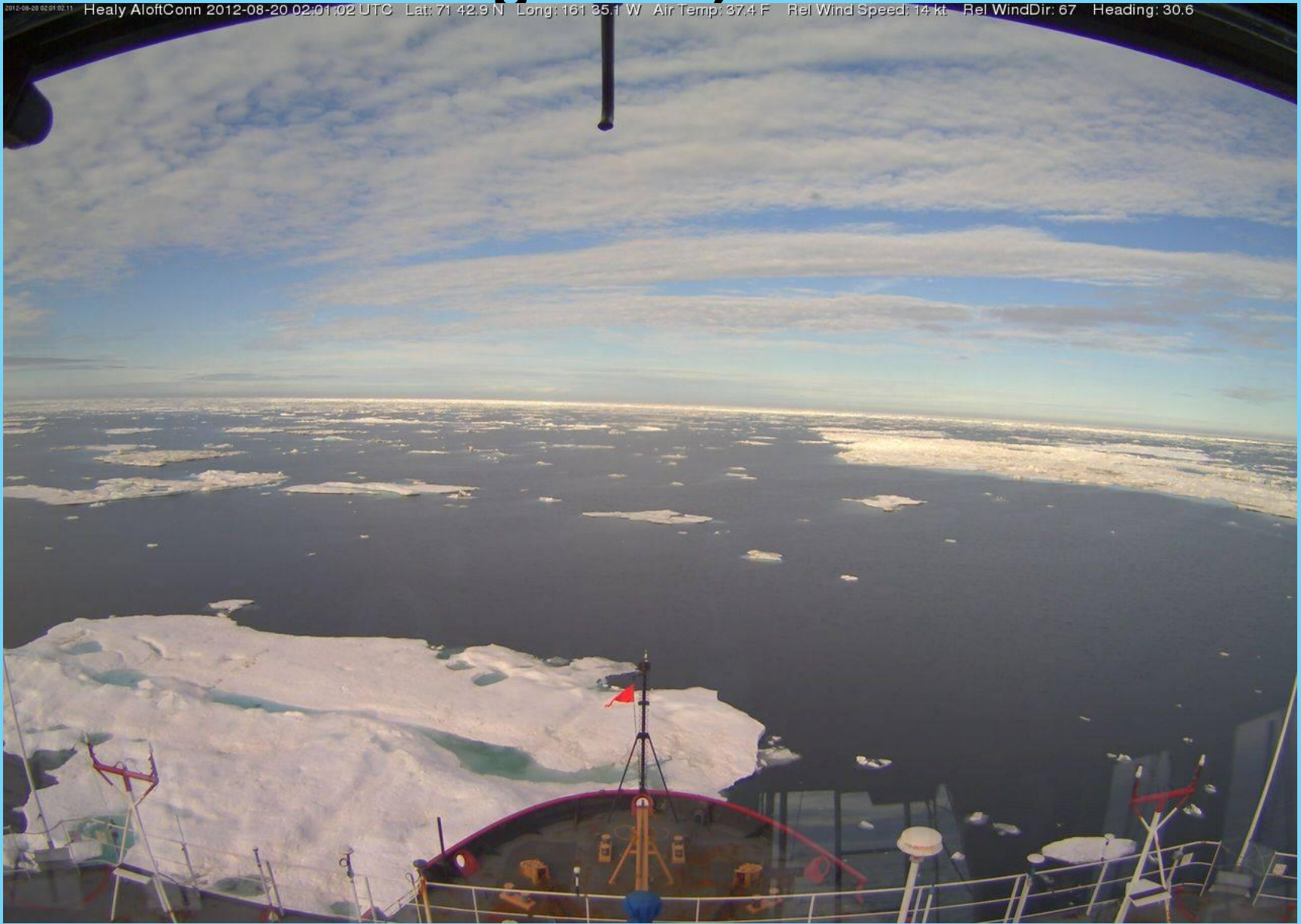


high

AD

Arctic sea ice breaks lowest extent on record

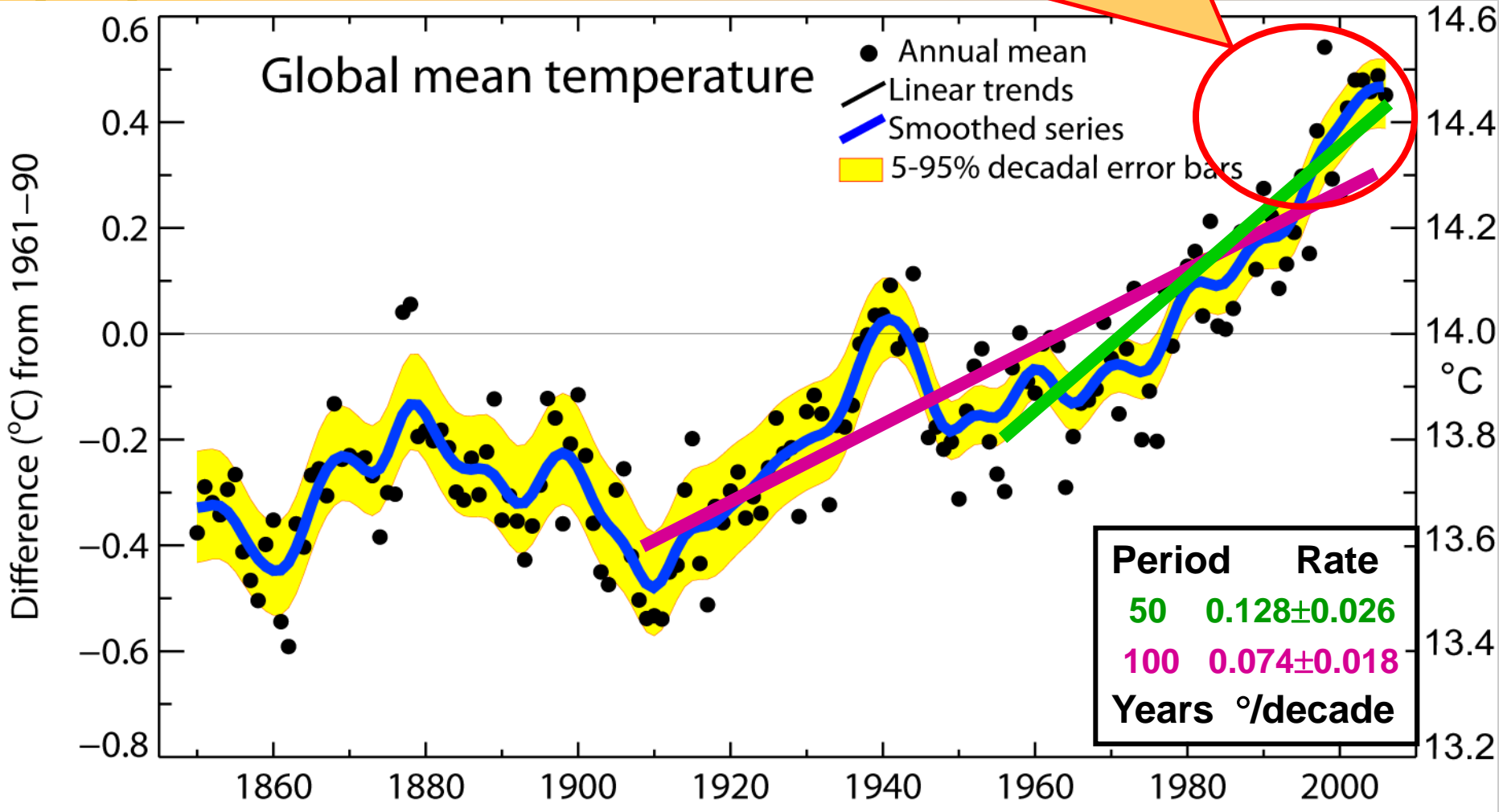
August 27, 2012





Global mean temperature

Warmest 12 years:
1998, 2005, 2003, 2002, 2004, 2006,
2001, 1997, 1995, 1999, 1990, 2000

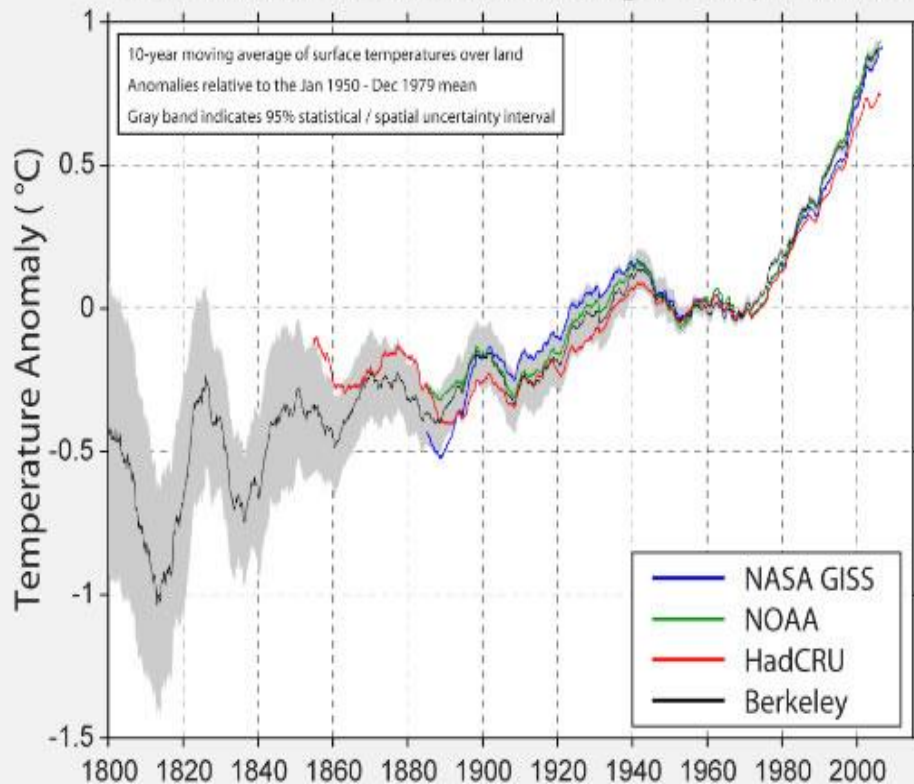


<http://berkeleyearth.org/>

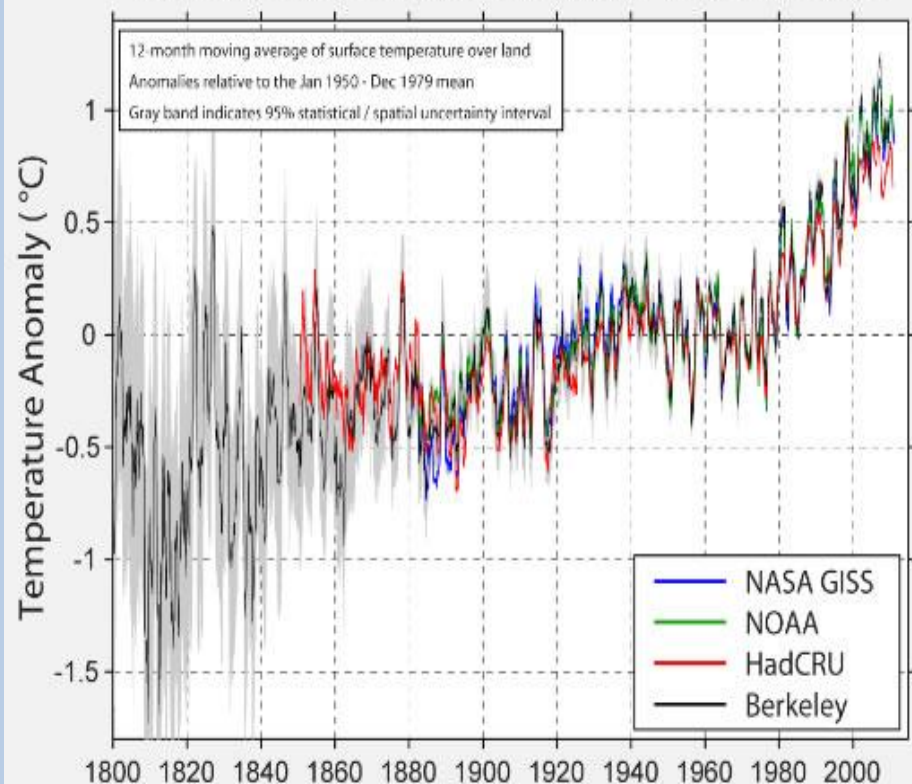
The scientific finding that settles the climate-change debate – Washington Post

Global warming study finds no grounds for climate sceptics' concerns – The Guardian UK

Decadal Land-Surface Average Temperature

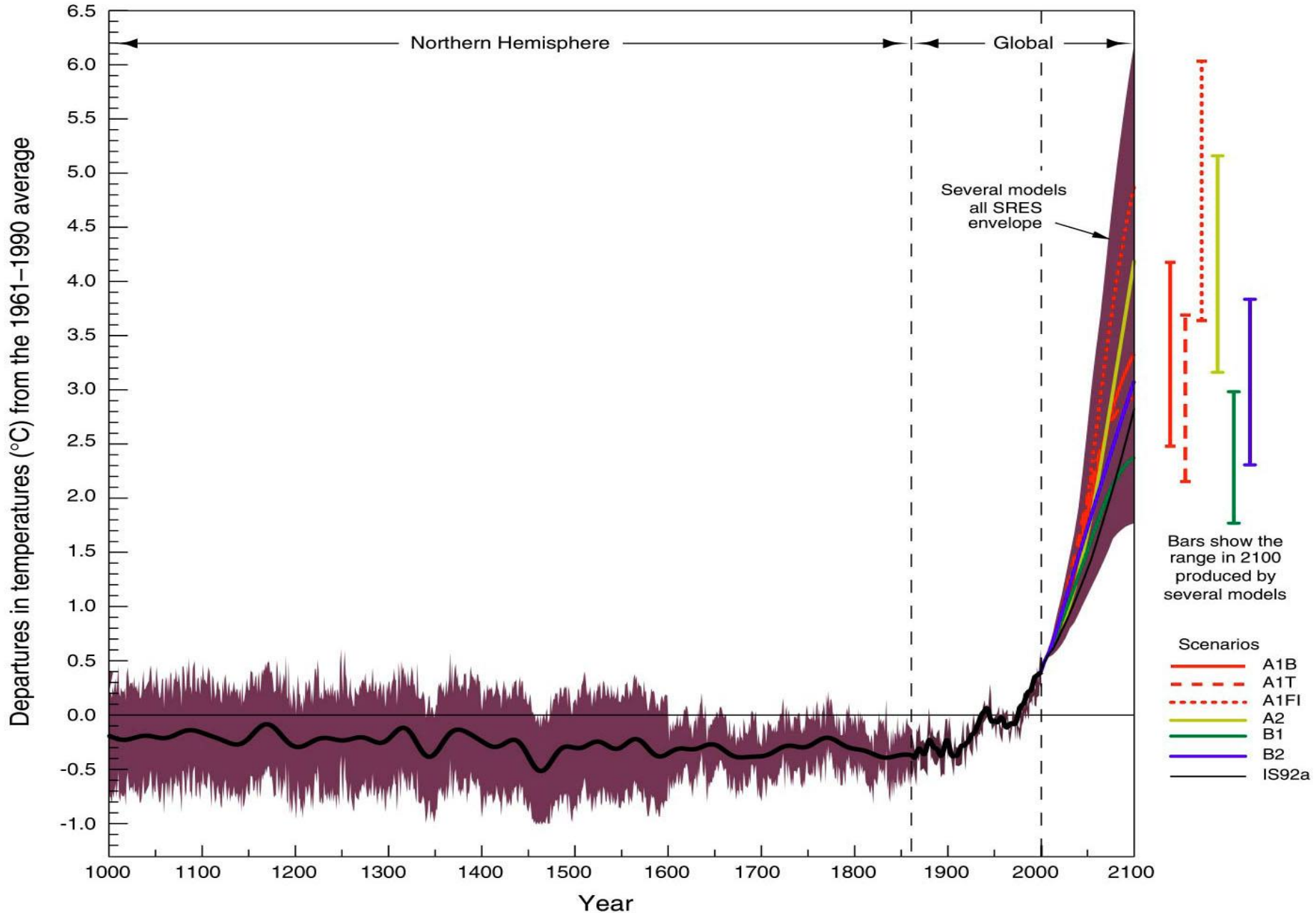


Annual Land-Surface Average Temperature



Variations of the Earth's surface temperature; 1000 to 2100

1000 to 1861, N.Hemisphere, proxy data; 1861 to 2000 Global, instrumental; 2000 to 2100, SRES projections



FIRST, ABOUT CLIMATE

**The Atmosphere is very
Small**

90% of new energy is in the oceans



WEATHER: Meteorological conditions
of the next *Day – Month*

CLIMATE: Long term conditions of the
Meteorology over *Years - Decades*

Carbon dioxide has risen by 36% since accurate measurements began in 1958

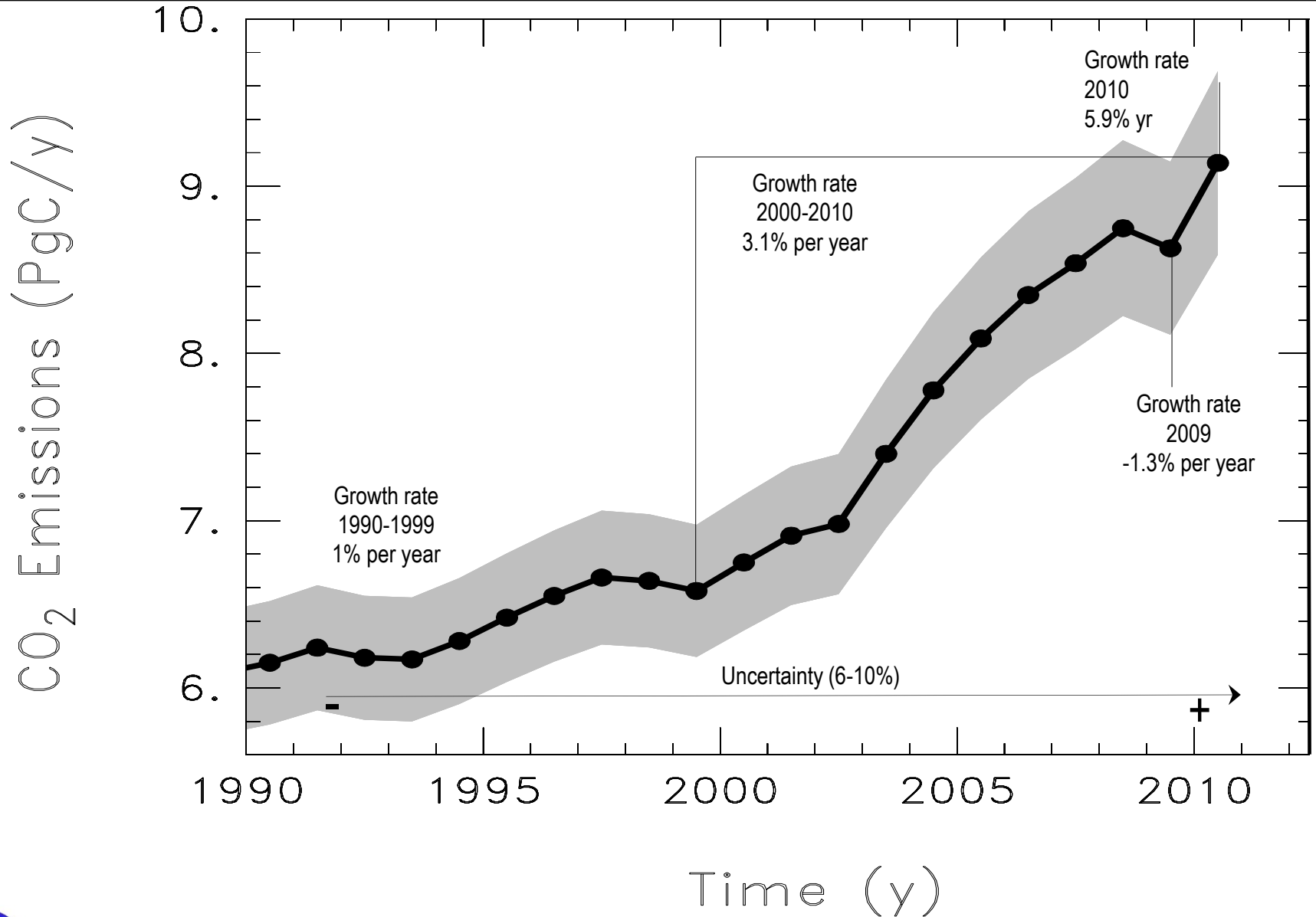


318 ppm (1958)

388 ppm (2008)

Mauna Loa Observatory on Hawai'i

Fossil Fuel & Cement CO₂ Emissions



Peters et al. 2011, Nature CC; Data: Boden, Marland, Andres-CDIAC 2011; Marland et al. 2009

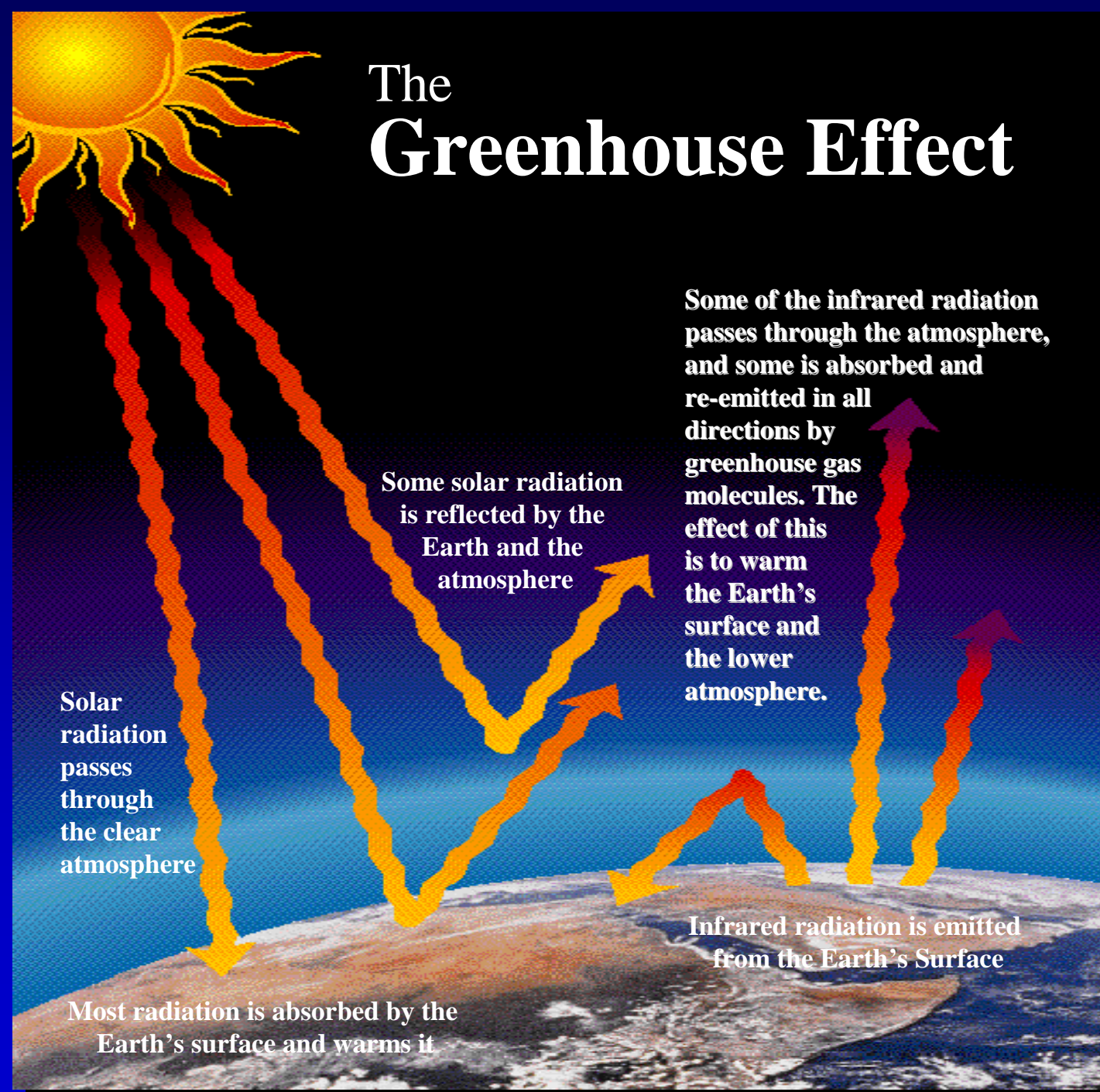




“The rise in CO_2 is proceeding so slowly that most of us today will, very likely, live out our lives without perceiving that a problem may exist”

Keeling CD, Harris TB, Wilkins EM, 1968. Concentration of atmospheric carbon dioxide at 500 and 700 millibars. J. Geophys. Res. 73:4511-28

The Greenhouse Effect



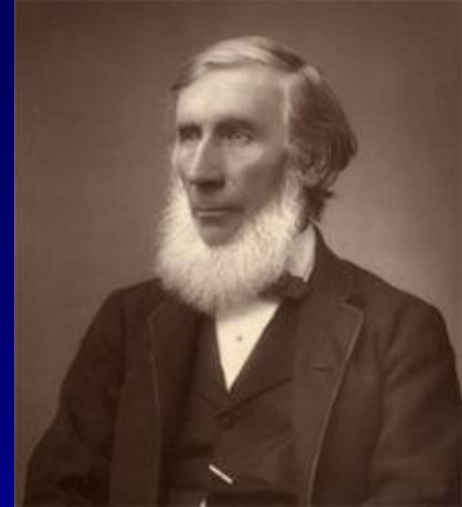
Solar radiation passes through the clear atmosphere

Some solar radiation is reflected by the Earth and the atmosphere

Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.

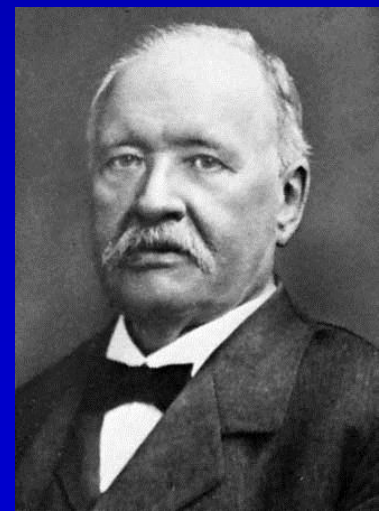
Infrared radiation is emitted from the Earth's Surface

Most radiation is absorbed by the Earth's surface and warms it



John Tyndall

Svante Arrhenius





Energy Transfer Mechanisms



Radiation



Conduction

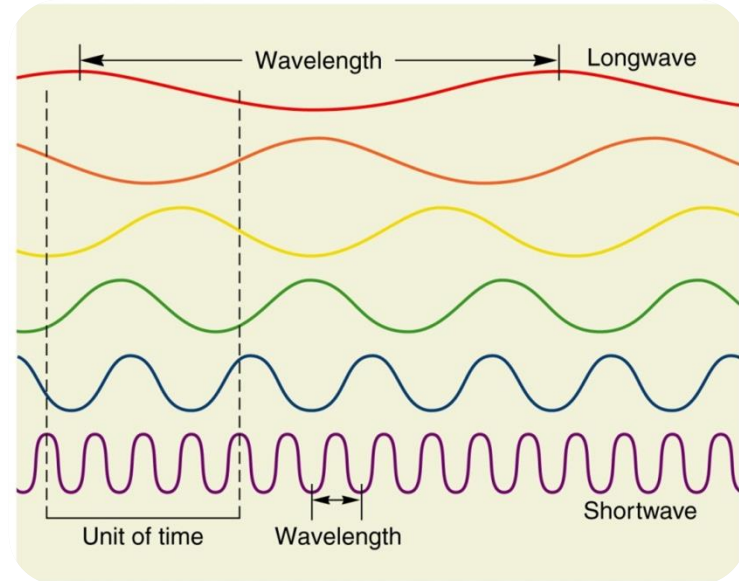


Convection



Electromagnetic (EM) Radiation

All objects emit electromagnetic radiation!!



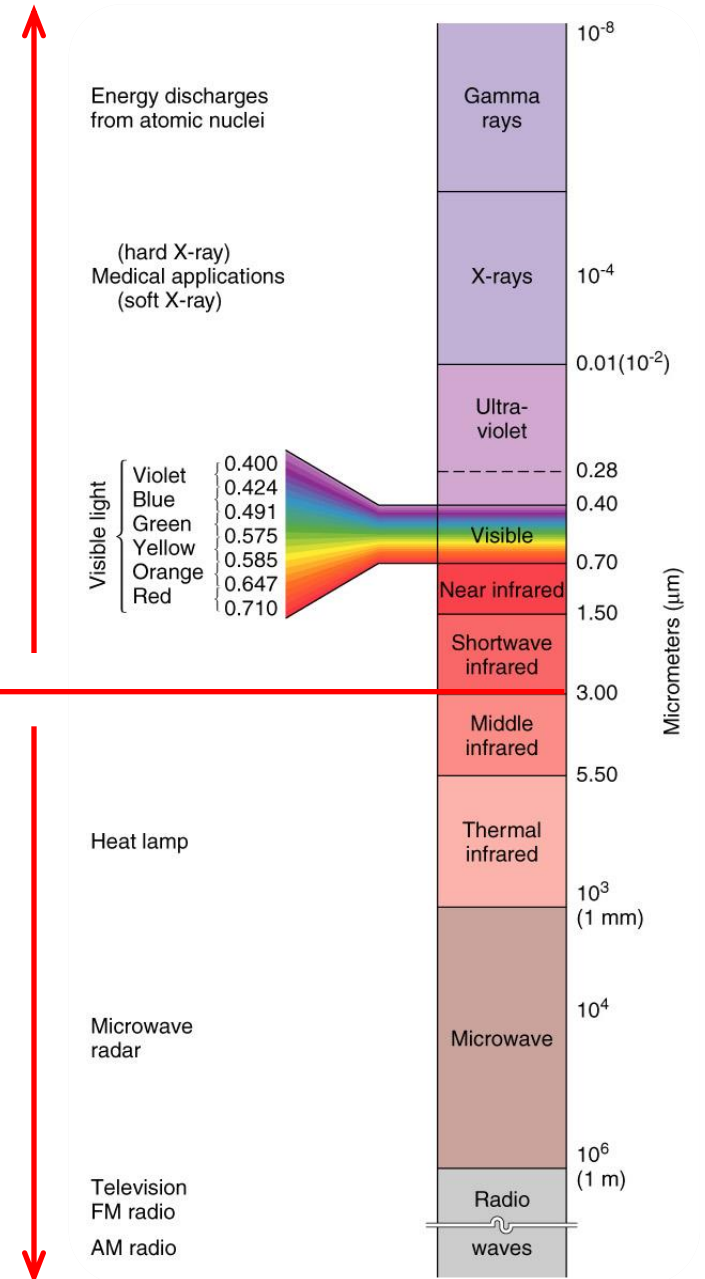
EM Spectrum

- **Shortwave Radiation**

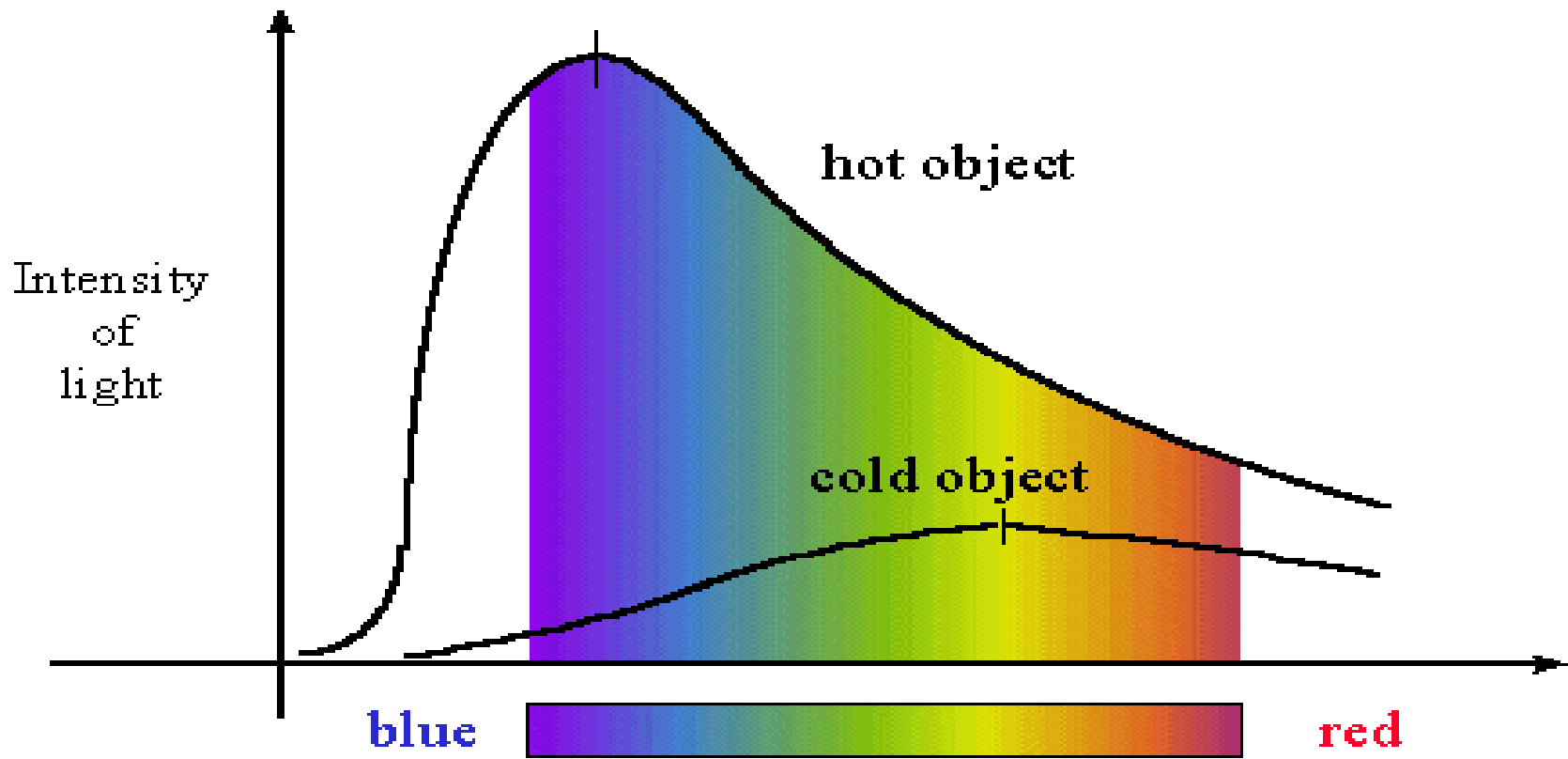
- Shorter than $3 \mu\text{m}$
- Visible, UV, x-rays, etc.
- Emitted from the Sun

- **Longwave Radiation**

- Longer than $3 \mu\text{m}$
- Thermal, microwave, radar, etc.
- Emitted from Earth

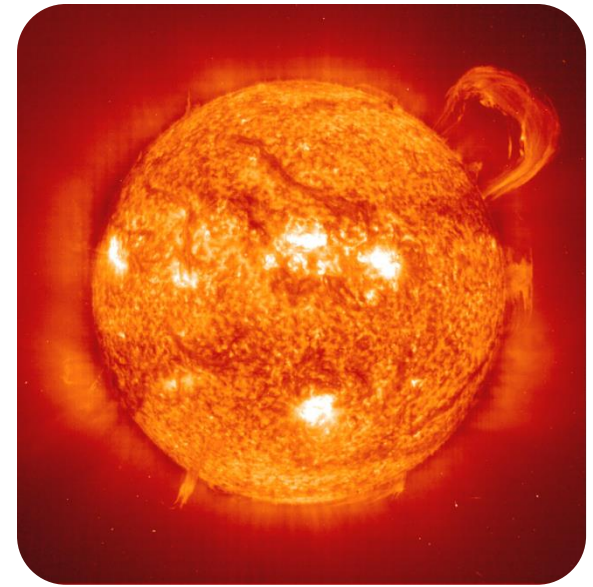


Wien's Law

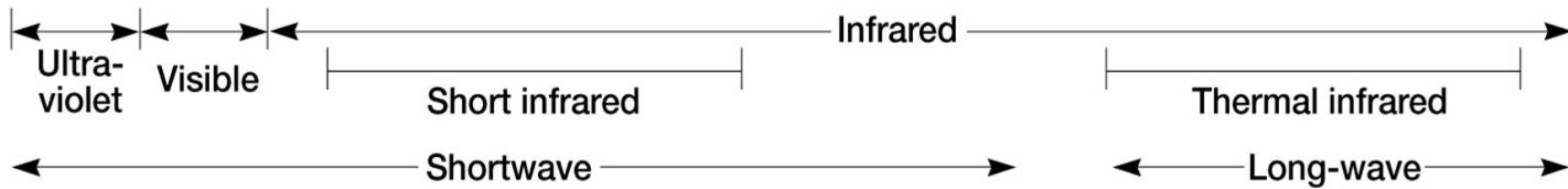
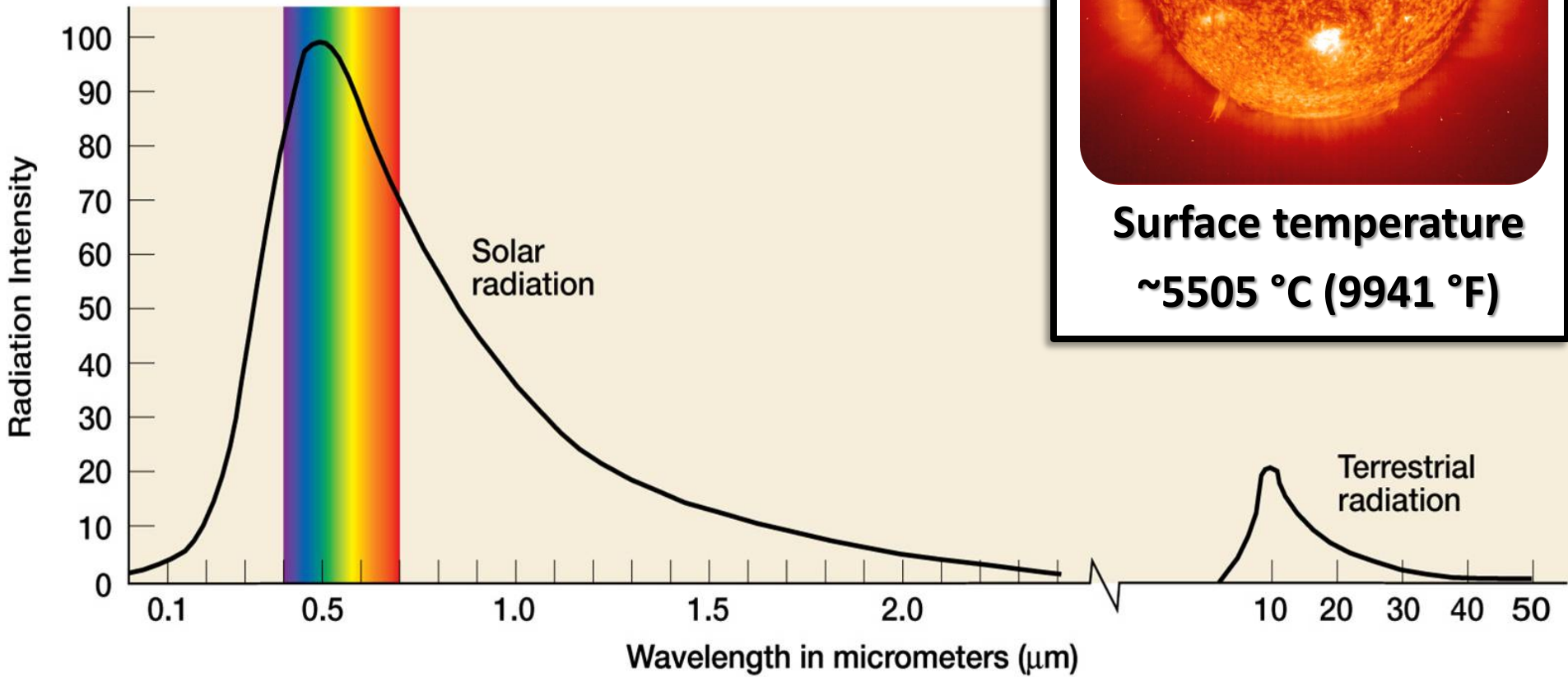


$$\text{Wavelength of Maximum Intensity (cm)} = \frac{.29}{T (^{\circ}\text{K})}$$

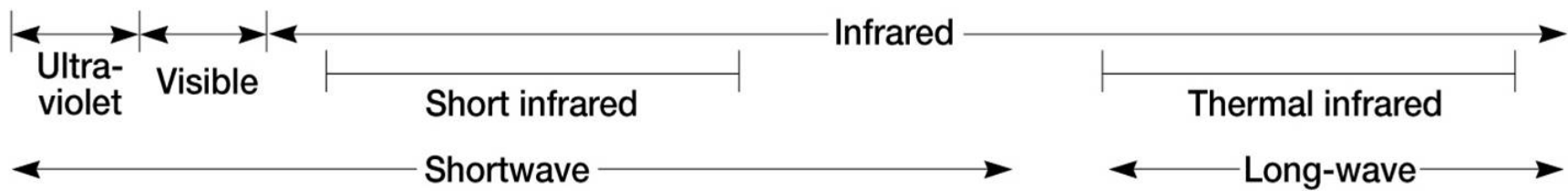
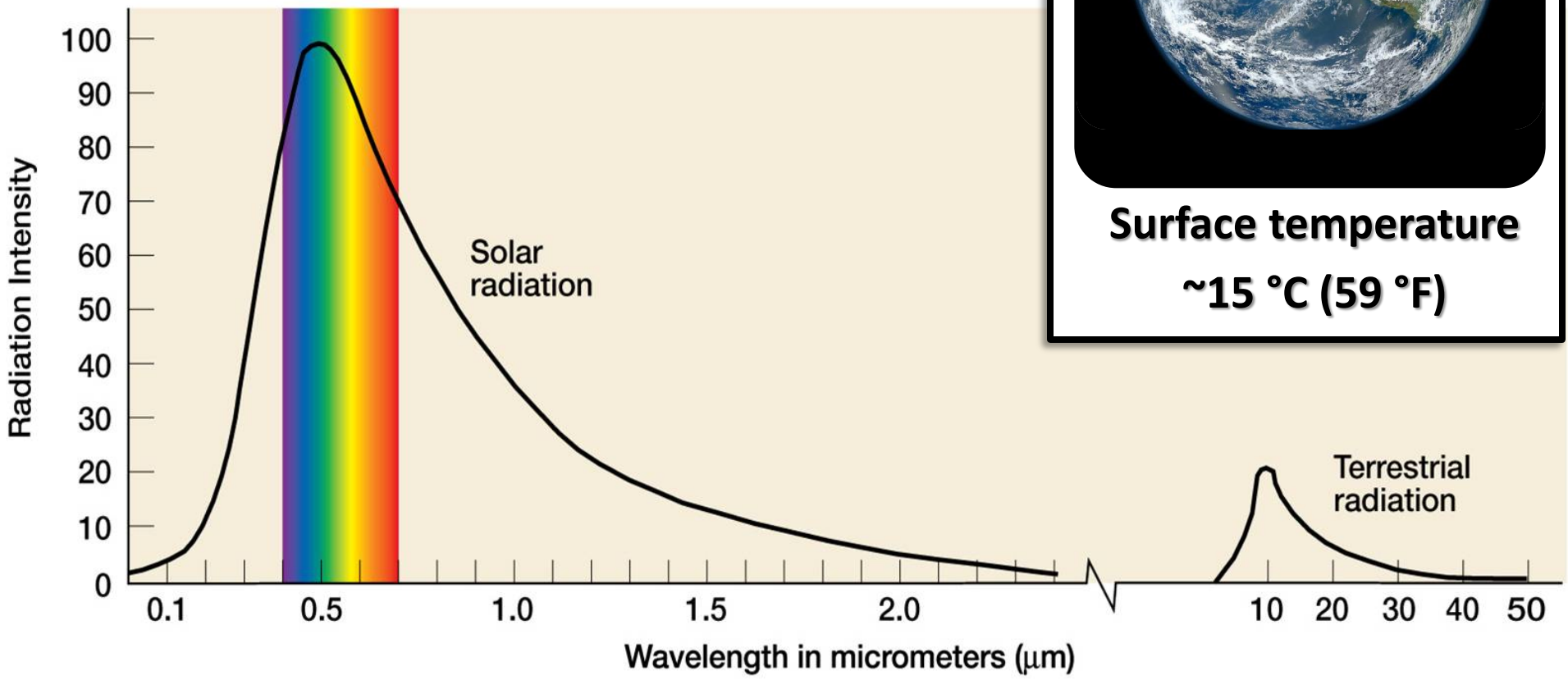
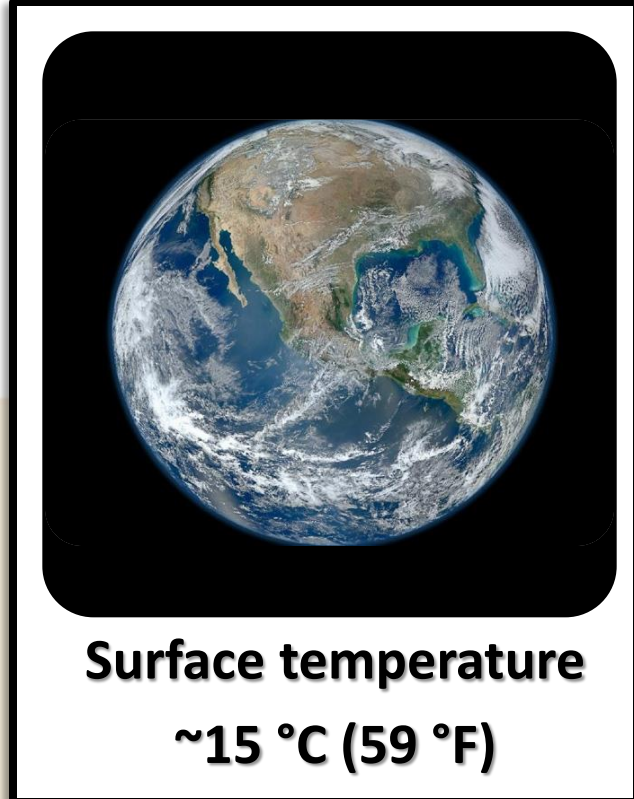
The Sun



Surface temperature
~5505 °C (9941 °F)

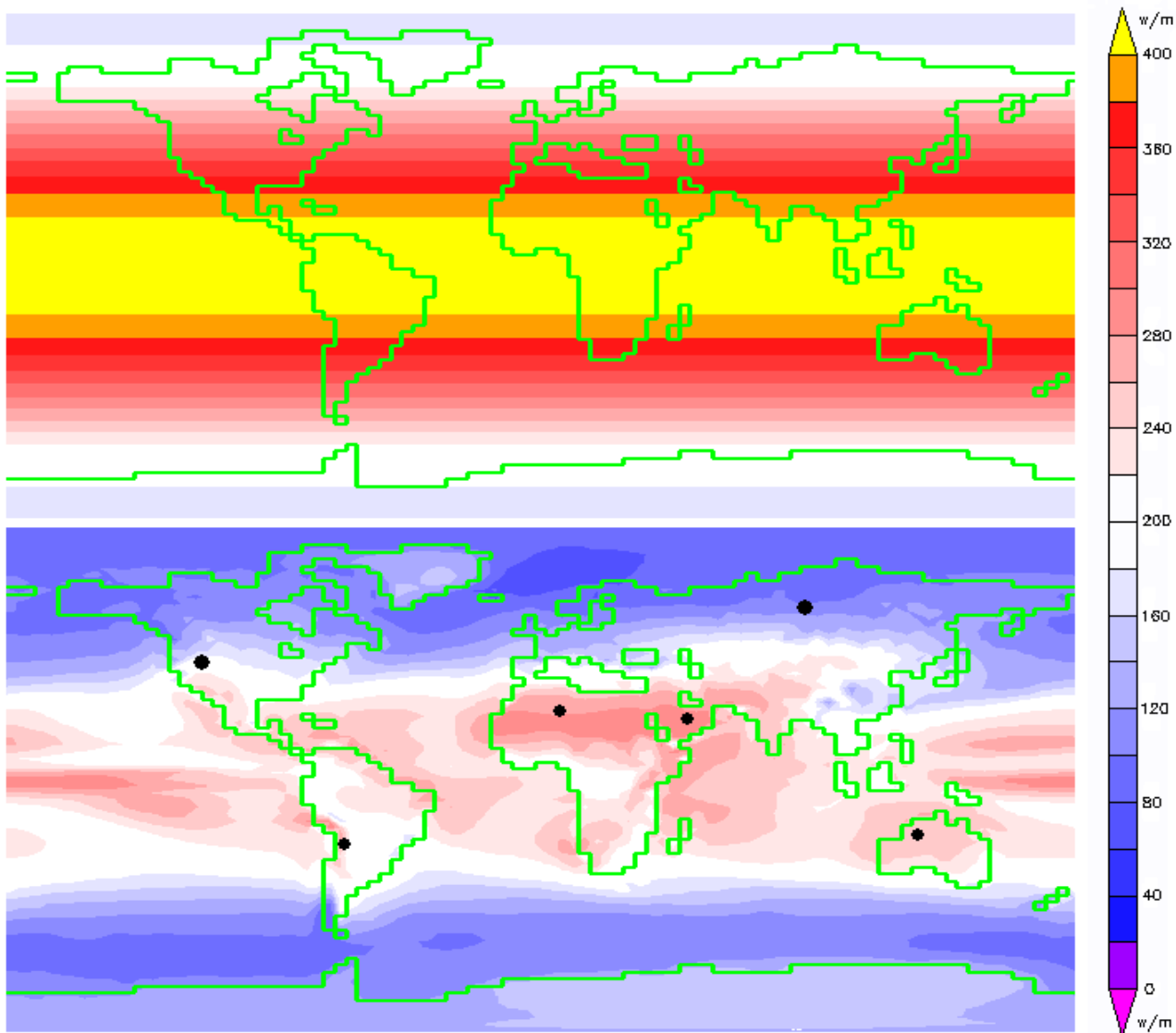


The Earth



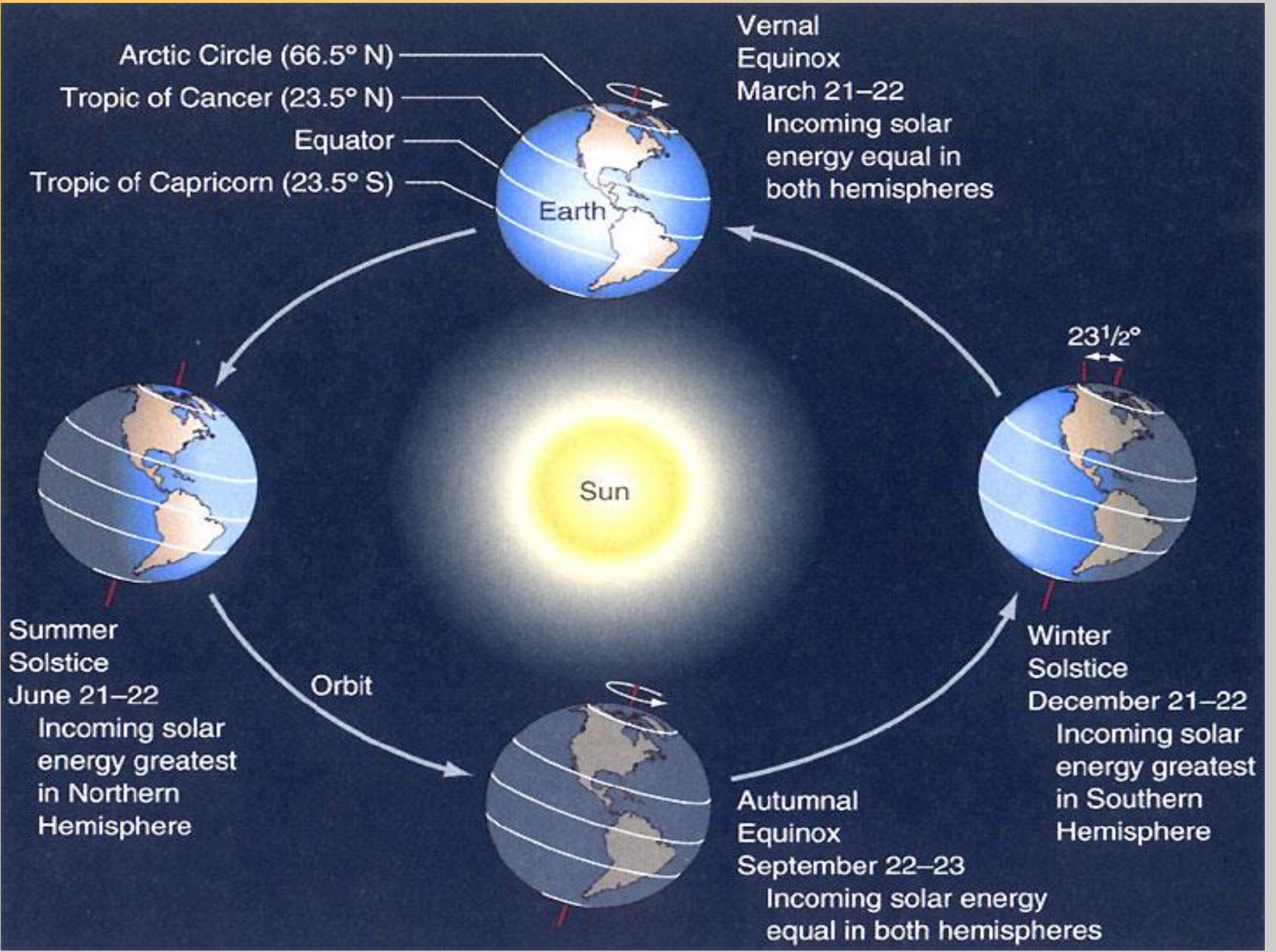


Annual Average Insolation



**Top
Of
Atmosphere**

**Earth's
Surface**



Arctic Circle (66.5° N)

Tropic of Cancer (23.5° N)

Equator

Tropic of Capricorn (23.5° S)

Earth

Vernal
Equinox

March 21–22

Incoming solar
energy equal in
both hemispheres

Sun

$23\frac{1}{2}^\circ$

Summer
Solstice

June 21–22

Incoming solar
energy greatest
in Northern
Hemisphere

Orbit

Winter
Solstice

December 21–22

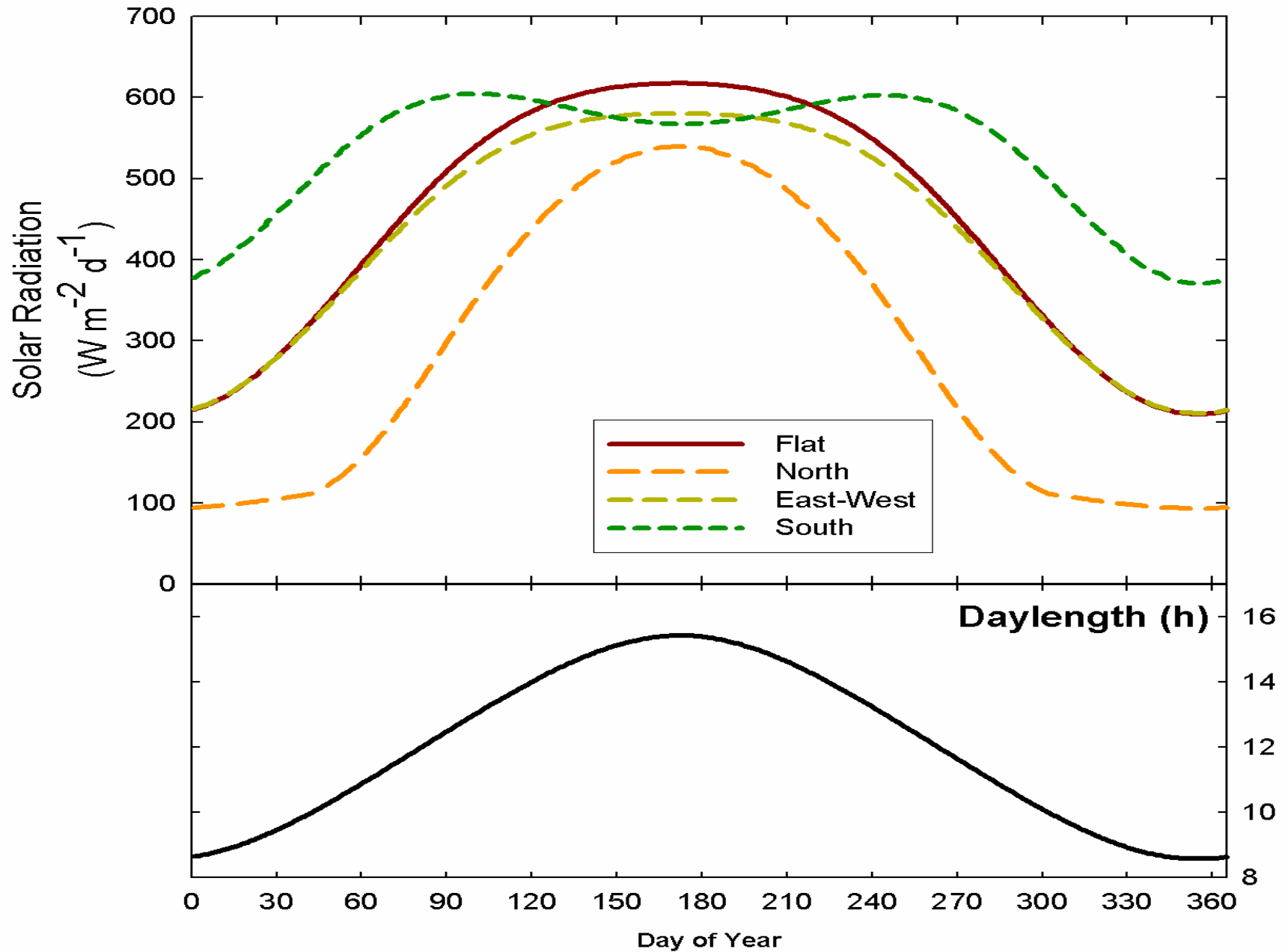
Incoming solar
energy greatest
in Southern
Hemisphere

Autumnal
Equinox

September 22–23

Incoming solar energy
equal in both hemispheres

Potential Incoming Solar Radiation (diffuse & direct) 45.0° N Latitude; 30° Slope



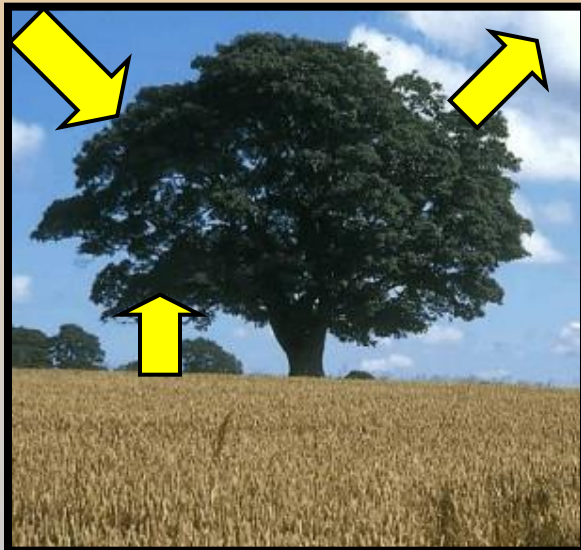


Important Radiation Laws & Concepts

Net radiation

Rn = incoming – outgoing

$$R_n = (1 - \alpha)I_s + E_L \sigma T^4(\text{surface}) - \sigma T^4(\text{sky})$$



α is *albedo*, which is the reflectivity of a surface

fresh snow has a high albedo (0.9)

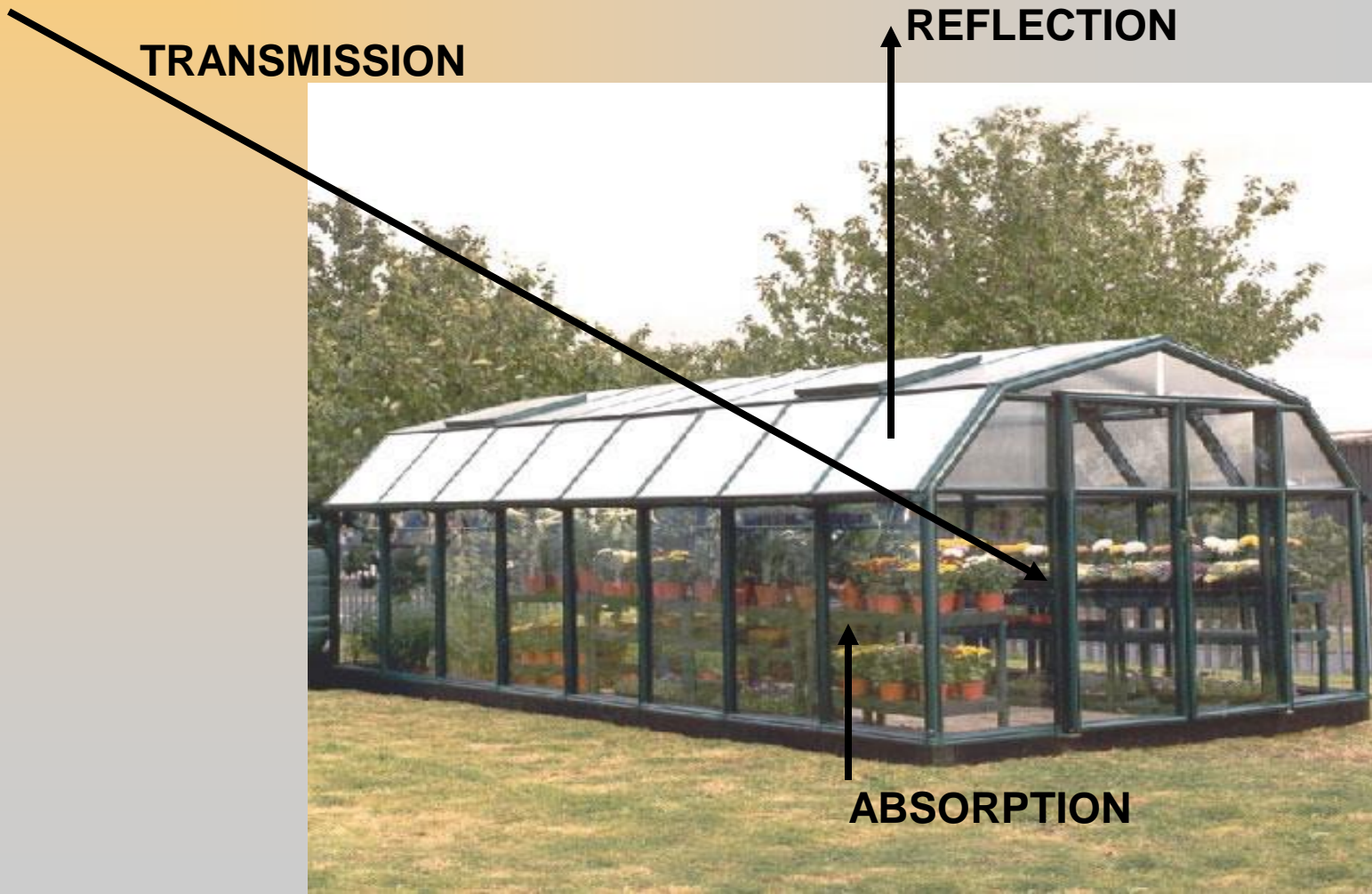
dark forest has a low albedo (0.05 – 0.15)

light colored soils are in between (0.4 – 0.5)

mean albedo for earth \approx 0.36



RADIATION TRANSFER



Albedo (Reflectivity)

Albedo values
(% reflected)

Moon
6%–8%

Water bodies
10%–60%
(varies with Sun altitude)

Earth's albedo
(average) 31%

Fresh snow
80%–95%

Forests
10%–20%

Crops, grasslands
10%–25%

Grass
25–30%

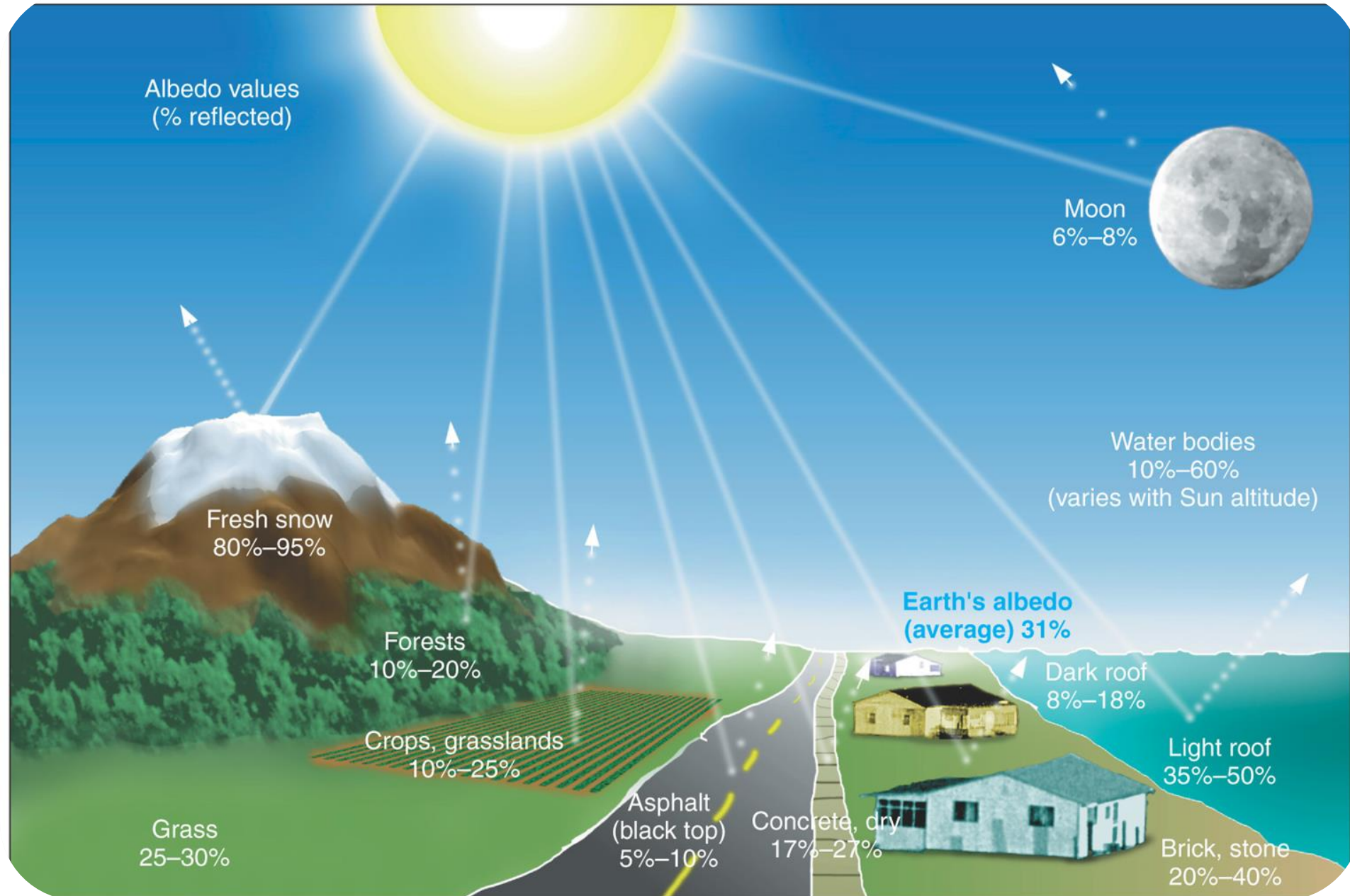
Asphalt
(black top)
5%–10%

Concrete, dry
17%–27%

Dark roof
8%–18%

Light roof
35%–50%

Brick, stone
20%–40%





Bowen Ratio



$$\beta = \frac{H}{\lambda E}$$

HEAT

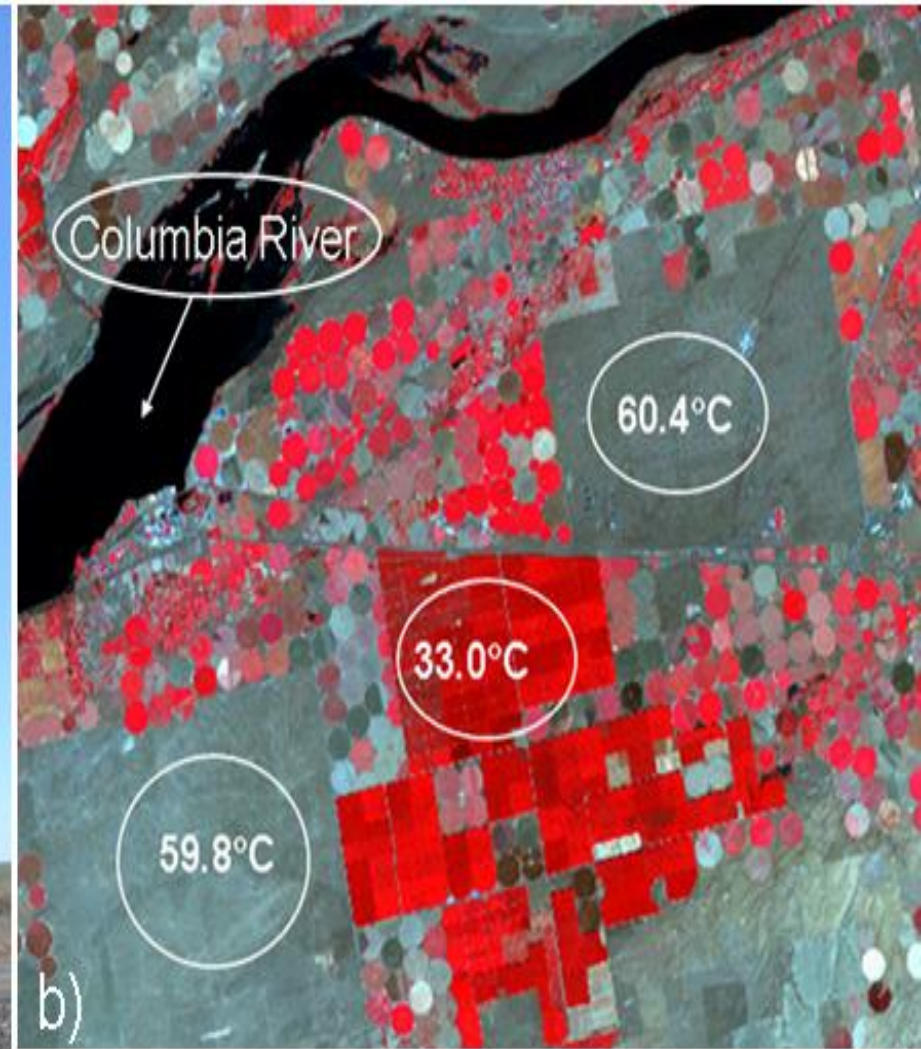
EVAPORATION



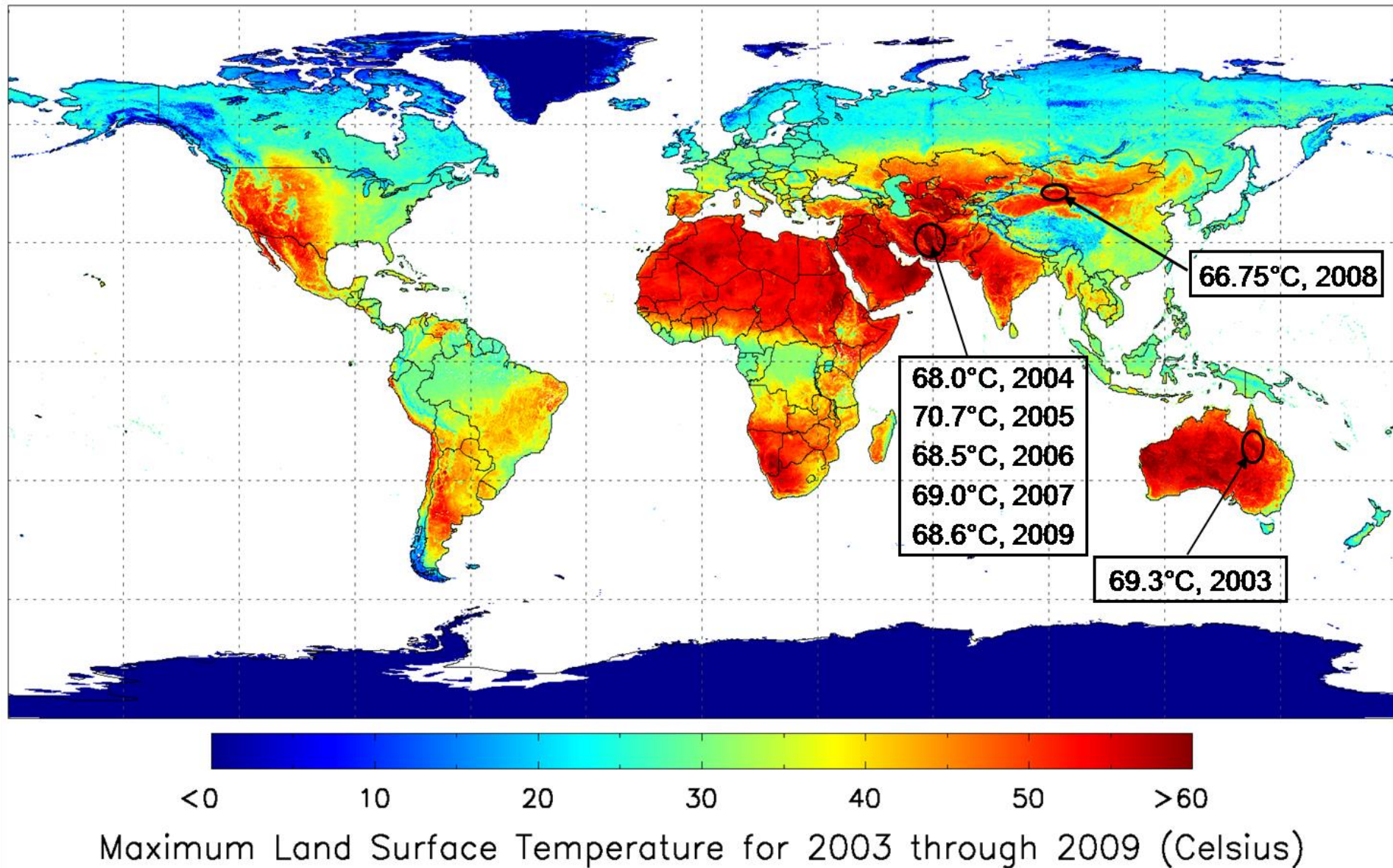
$$\beta = \frac{10}{1} = 10$$

$$\beta = \frac{10}{100} = 0.1$$

Comparison of Land Surface Temperatures from Aqua MODIS Irrigated Poplar vs arid Sagebrush, central Oregon



Aqua MODIS Maximum Annual Land Surface Temperature (2003-2009)



LUT DESERT, IRAN, HOTTEST PLACE ON EARTH, 70DEG C



The Greenhouse Effect



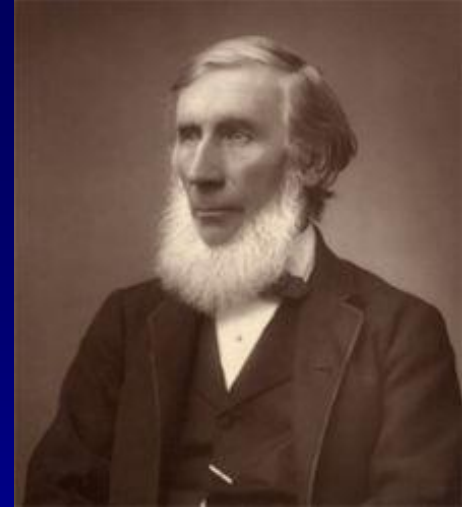
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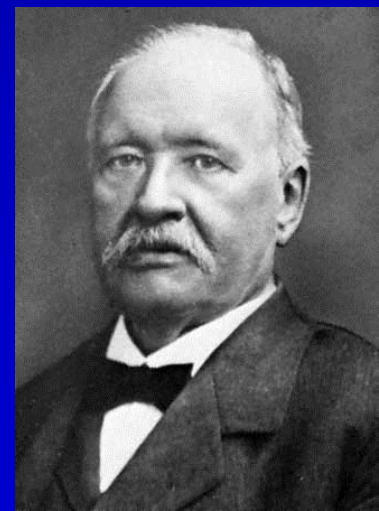
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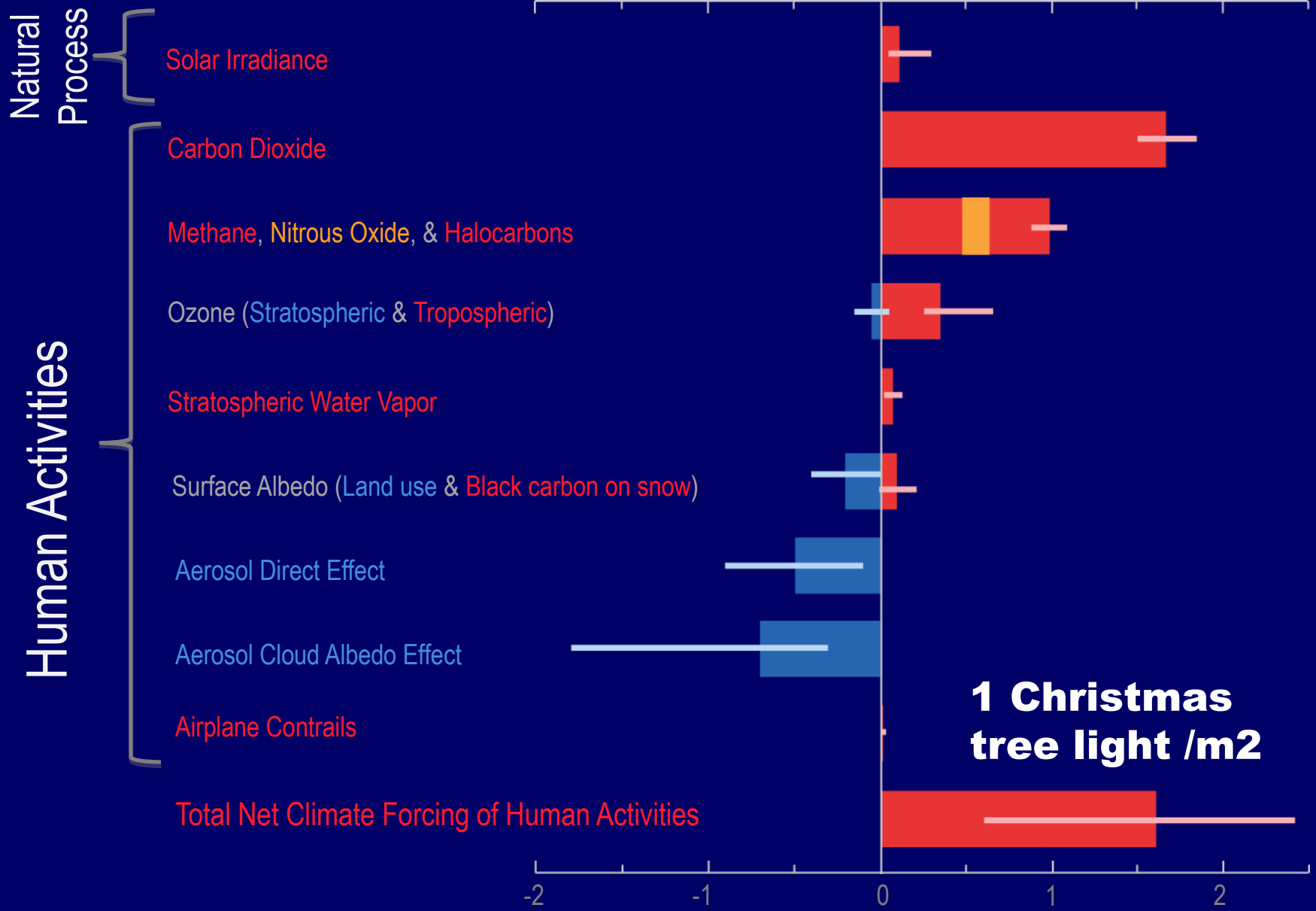


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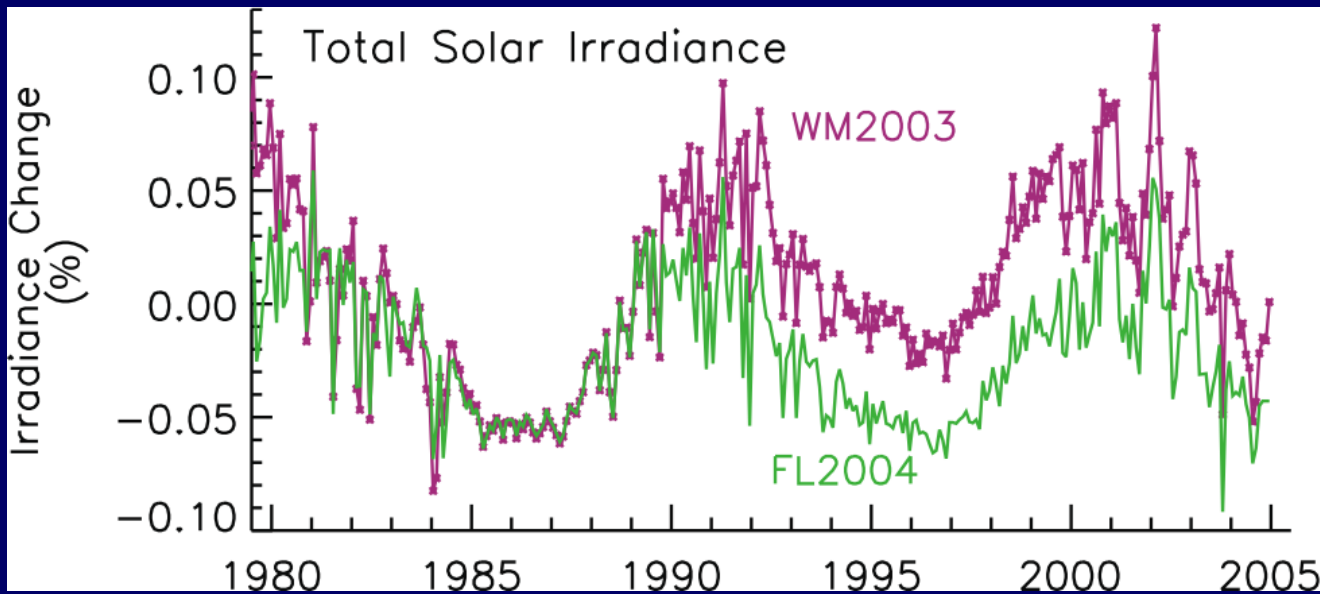
Relative measures of Earth's climate forcings



1 Christmas tree light /m2

Radiative Forcing (watts per square meter)
IPCC - WGI

Better and longer satellite data about the Sun



Improved assessment:

a) no observed trend in solar irradiance since 1978 using high quality inter-calibrated data; b) spectral information c) solar magnetic flux model rather than proxy data; d) re-evaluation of variations in Sun-like stars.

Solar irradiance forcing much smaller than GHG.

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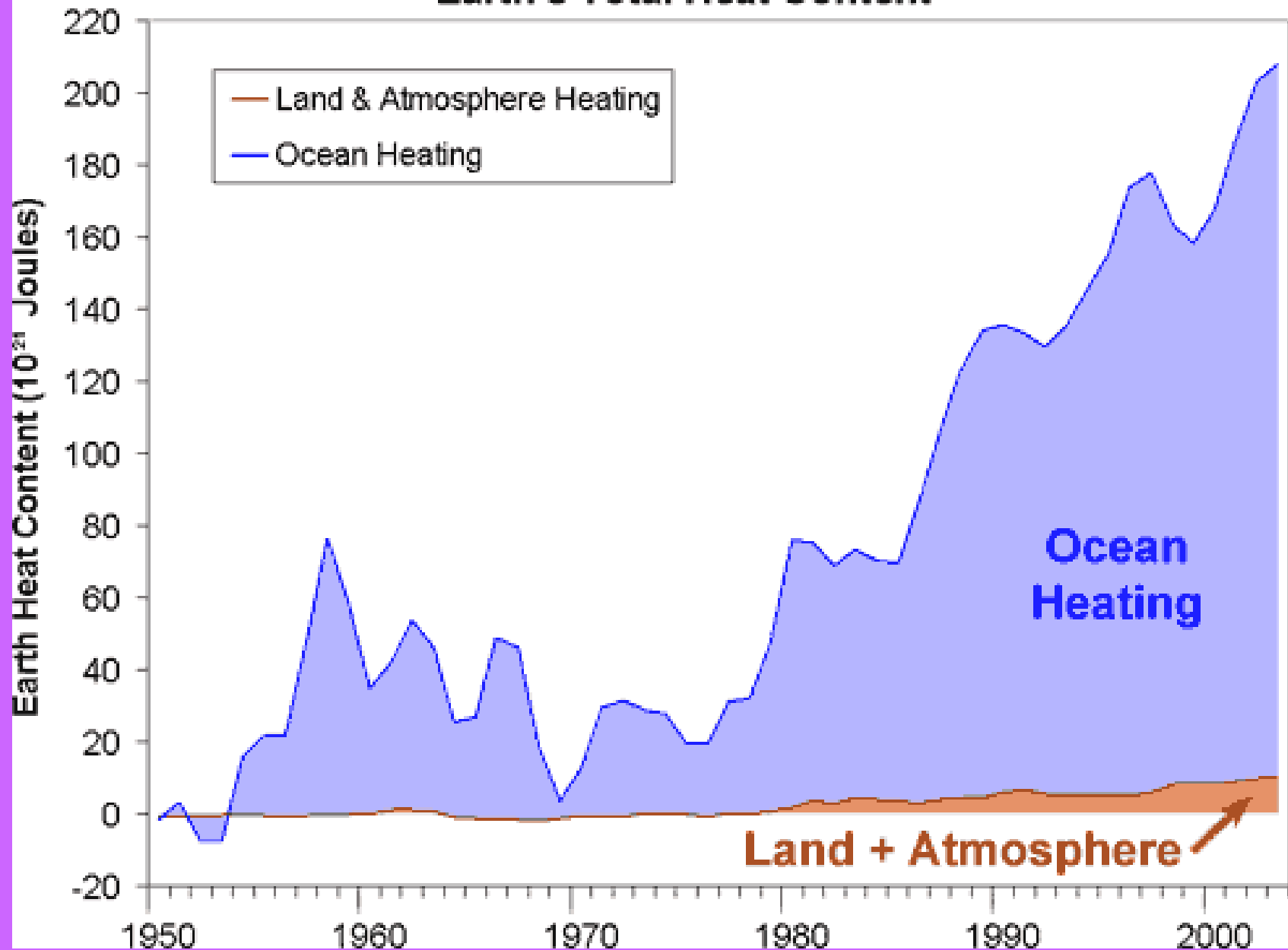


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388 ppm (2008)

Mauna Loa Observatory on Hawai'i

Earth's Total Heat Content



Data From Murphy et al 2009, Domingues et al 2008

Graph from <http://www.skepticalscience.com/>